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FIFTH QUARTERLY PROGRESS REPORT

1 JULY 1977 TO 30 SEPTEMBER 1977

CONTRACT DAAB07 - 76 - C - 0041 ✓

MANUFACTURING METHODS AND TECHNIQUES FOR MINIATURE  
HIGH VOLTAGE HYBRID MULTIPLIER MODULES

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# FIFTH QUARTERLY PROGRESS REPORT

1 JULY 1977 TO 30 SEPTEMBER 1977

## MANUFACTURING METHODS AND TECHNIQUES FOR MINIATURE HIGH VOLTAGE HYBRID MULTIPLIER MODULES

CONTRACT NO. DAAB07 - 76 - C - 0041

PREPARED BY: DR. MICHAEL KORWIN - PAWLOWSKI

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# ABSTRACT

The progress made during the fifth quarter of work on the Manufacturing and Technology Program for Miniature High Voltage Multiplier Modules is described in this report.

The results of electrical performance testing at the room, high (+52°C) and low (-54°C) temperatures as well as effects of thermal shock, and high and low temperature storage are presented.

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## PURPOSE

This Contract covers component designs, mounting and interconnection techniques, tooling and test methods and other manufacturing methods and techniques required for production of rectangular and curved miniature high voltage multiplier modules. These units are to be used in low cost power supplies for second generation image intensifier tubes. The full scope and details of the specification are given in SCS - 495, Appendix A to the First Quarterly Report.

Major milestones in this program consist of delivery of the following items:

- (1) First and second engineering samples and test data.
- (2) Production line layout and schedule.
- (3) Confirmatory samples and test data.
- (4) Production line set - up.
- (5) Pilot production run.
- (6) Production rate demonstration.
- (7) Preparation and publication of a final report.

The general approach is to design and set - up a cost - effective production capability, utilizing already established device technologies and materials, and to demonstrate the production line capability to fabricate at the rate of 125 acceptable units per 40 hour week.

## GLOSSARY OF SPECIAL TERMS

- Capacitor bank: - Ceramic wafer with metallizations which perform the function of a number of capacitors connected in parallel (parallel bank) or in series (series capacitor bank).
- Cure: - To change the physical properties of a material by chemical reaction or by the action of heat and catalyst.
- Flash test: - Test consisting of instantaneous application of voltage at its specified value to the part.
- Hybrid: - Technology combining thick - films (capacitor banks) with discrete devices (rectifiers).
- Multiplier Modules: - Device consisting of capacitor banks and rectifiers connected and packaged to perform voltage multiplication and rectification.
- Pad: - The metallized area on the ceramic bank acting as a plate of a capacitor and used to make an electrical connection to it.
- Rectifier: - Semiconductor device with one or more p - n junctions connected in series.

Rectifier -  
substrate  
Assembly:

- A substrate with rectifiers placed and secured within it.

Substrate:

- Part of a multiplier module consisting of a piece of insulating material machined to accommodate the rectifiers and support the capacitor banks.

### LIST OF SYMBOLS AND ABBREVIATIONS

$i_c$	-	charging current ( $\mu A$ )
$C_x$	-	measured capacitance (pF)
D.F.	-	dissipation factor (%)
$f$	-	frequency (KHz)
$C_i$	-	input capacitance (pF)
$I_L$	-	load current (nA)
$v_r$	-	ripple voltage (V)
$V_B$	-	breakdown voltage (V)
$V_i$	-	input voltage ( $V_p - p$ )
$V_o$	-	output voltage (V d.c.)
$\eta$	-	efficiency (%)

## 1. INTRODUCTION

This Fifth Quarterly Report describes briefly the progress in the Manufacturing Methods and Techniques for Miniature High Voltage Hybrid Multiplier Modules Program, made during the period from 1 July to 30 September 1977.

In the First Quarterly Report the design and the manufacturing process for rectangular and curved multiplier modules were described. Prototype rectifier-substrate assemblies were fabricated and then redesigned to simplify the assembly operation. The specification covering the requirements for the multiplier modules forms Appendix A of the Report.

In the Second Quarterly Report results of the electrical evaluation of the first sample batch of rectangular capacitor banks TSK 25 - 250 and TSK 25 - 251 were given, the choice of the rectifier was made and electrical test results were presented on non-modular multipliers fabricated with TSK 25 - 250 and TSK 25 - 251 capacitor banks and Erie's standard HV20PD four-junction rectifiers, to evaluate these components.

In the Third Quarterly Report results of electrical tests on rectangular multiplier modules were presented. For an input voltage of 1 KV, efficiencies above 96% under no-load conditions and above 95% with 500 nA load currents were achieved for all multipliers assembled with TSK 25 - 250 and TSK 25 - 251 and three-chip rectifiers. Good ripple voltages, input capacitances and charging currents were

also measured on these multipliers. Results of the mechanical and electrical evaluation of TSK 25 - 249 curved capacitor banks were also presented in the Third Quarterly Report.

In the Fourth Quarterly Report work on impregnation and coating of the multipliers was discussed as well as some problems associated with the fabrication of the rectifier-substrate assemblies. The fabrication of rectangular and curved multipliers for the First Engineering Sample was discussed.

## 2. FABRICATION AND EVALUATION OF MULTIPLIERS

The 26 rectangular (TSK 312 - 000) and 4 curved (TSK 313 - 000) multipliers fabricated during the previous quarter were subjected to a series of electrical tests the results of which are given in Tables 1 and 2. The operational test circuit is given in the Second Quarterly Report (Fig. 5), and the test circuit for input capacitance and charging current is given in Appendix A (Fig. 2) of the First Quarterly Report. The devices performed satisfactorily as far as the efficiency was concerned. With no load the efficiencies of all multipliers were above 97.5% and with a 500 nA load current above 96.7%, well above the 85% level required.

An overvoltage test was done on 10 rectangular multipliers with 3 devices being able to operate without external arcing with an input voltage of 1500 V, 3 others with input voltage up to 1300 V and the remainder with the input voltage up to 1100 V. The testing of the multipliers was done in air, in order to ascertain the safe operation limits of the devices without additional potting or use of dielectric liquids. Testing in air resulted, in some cases, in the formation of char marks on the sides of the capacitor between the ground and input leads. In the future multipliers will be tested immersed in a dielectric liquid.

The results showed that 9 out of 10 rectangular multipliers did not arc in air with 1500 Vp-p applied at the input. Two rectangular (Units #38 and 47) and one curved (Unit #1) multiplier broke down while being tested in air. Of the remaining devices,

12 rectangular and 3 curved multipliers were sent to Night Vision Laboratory, Ft. Belvoir as partial submission of the First Engineering sample and 13 rectangular multipliers were kept for testing to the Second Engineering sample requirements. Upon completion of these tests and receiving approval of the First Engineering sample, the next Engineering sample batch of rectangular multipliers will be manufactured.

The results of tests on the ten devices retained from the First Engineering Sample lot of rectangular multipliers are given in Table 3. At  $52^{\circ}\text{C}$  all the devices show only a 50 volts decrease of the output voltage in comparison with the  $25^{\circ}\text{C}$  values of 5850 V for no-load condition and 5800 V with a 500 nA load current. At  $-54^{\circ}\text{C}$  the output voltage is the same as at room temperature. The input voltage in all cases was 1000V. The specification SCS - 495 allows for a  $\pm 2\%$  temperature change of efficiency. We were not able to measure the input capacitance at high and low temperatures due to excessive stray capacitance of the long cable connections to the devices in the temperature chamber. The charging current and ripple voltage measurements on representative samples will be made on the next lot. The devices were subjected to a series of 25 cycles of thermal shocks as per MIL - STD - 202, 107D, B - 1 with a 30 minute stabilization at each extreme of  $-65^{\circ}\text{C}$  and  $+71^{\circ}\text{C}$ . The output voltages were measured at  $25^{\circ}\text{C}$  with no-load and with a 500 nA load current as, correspondingly, 5800 V and 5750 V. One multiplier was eliminated from further tests due to surface arcing. The remaining 19 pieces

were subjected to 8 hrs., of non-operational storage at 70° C and 2 hrs., at -65° C. The output voltage remained unchanged after these tests. Generally speaking the performance of these devices in the current series of tests was good and they will be submitted as part of the Second Engineering sample. Eleven rectangular and 3 curved multipliers from the First Engineering sample was returned from the Night Vision Laboratory, Ft. Belvoir, after undergoing testing to the First Engineering sample requirements. The tests generally confirmed measurements done at the Trenton plant. The results were compared and discussed during the Program Review Meeting on August 23 - 24, 1977. These devices will be tested to the Second Engineering sample requirements together with the curved multipliers now in production.

The batch of 15 curved multipliers fabricated in the previous quarter was scrapped because mis-screening of the electrode pads on capacitors resulted in open-circuits in the multipliers. We have ordered another 125 pcs. lot of TSK 25 - 260 curved capacitor banks from Erie Technological Products Inc., Erie, Pa. to replace the defective units. We have also ordered 100 each TSK 25 - 250 and TSK 25 - 251 rectangular capacitor banks. All 3 lots were received on 24 August 1977. Fifty glass-epoxy substrates were made in our model-shop and a batch of 296 rectifiers bringing the total number of rectifiers made in this program to 1681.

The results of electrical tests and dimension measurements for the rectangular capacitor banks were very much the same as those obtained for the previous lot of June 1, 1977.

We were advised by the manufacturer that the problems previously encountered with the curved bank capacitors TSK 25 - 260 had been corrected. A new screen was made having smaller pad areas, thus reducing the capacitance to 80 - 90 pF @ 1 V<sub>RMS</sub>/ 1 kHz. Also, a new fixture was designed to facilitate registration.

The results of tests done on the 125 pcs. lot received on August 24 in essence confirms this, although there were still some dimensional discrepancies - the most important concerned the angle width of the annular segment forming the capacitor which was measured on two samples as 83° and 82°31' rather than the specified 80°.

The results of testing of the curved capacitor banks are given in Tables 4 and 5 and on Fig. 1 and 2.

A batch of 28 curved rectifier-substrate assemblies was started in August from which we lost 2 at lapping. We started assembling 18 multipliers with the TSK 25 - 260 capacitors received on August 24 and we lost 4 multipliers in the process: 3 at assembly and 1 at coating. Out of 15 devices, we assembled 7 at the first try, while 8 needed to be redone due to misalignment of the capacitor pads with the rectifiers, resulting in open-circuits in the rectifier chain.

We reworked the multipliers by reapplying the conductive epoxy to the capacitor pads after detaching them from the substrate assemblies with a razor blade. In the

process we lost 2 capacitors and probably shorted one multiplier applying too much epoxy.

A general observation is that the assembly of curved multipliers is much more difficult than is the case with the rectangular ones, due mainly to the difficulty of holding the parts, and of aligning capacitors and the substrates.

The body thickness of the multipliers after coating was in the range of .139 " to .149 ". Measured at the leads and including both lead solder contacts it was .151 " to .168 ". When the impregnating compound is oven - cured, with the multipliers suspended, a bulge of the compound forms at the lower end of the device - we found it very difficult to keep the thickness at this bulge below .175 " with the maximum of .180 ".

Fourteen curved multipliers were transferred to Q.C. for testing.

Quotations were received from outside suppliers for the glass - epoxy substrates. Sample orders of 100 pcs. each of TSK 312 - 104 and TSK 313 - 104 substrates were placed with Laser - Tech. Ltd., Scarborough, Ontario, to be delivered by September 25, 1977. We were later advised that due to manufacturing problems these substrates will not be ready before mid - October 1977. Minor changes were introduced in the drawings of the substrates ordered compared with those used for in - house production. The new drawings are given in Fig. 3 and 4.

The technique of lapping the rectifier-substrate assemblies using a Lapmaster 12 machine and an oil-carborundum lapping compound seems to be working satisfactorily. Our model shop fabricated for us 2 more lapping jigs which will increase our lapping capacity from 12 to 36 curved multipliers at a time.

### 3. CONCLUSIONS

The multipliers fabricated in the latest batch performed electrically very well under the tests both at normal and environmental-stress conditions. The curved multipliers show however high input capacitance - this would be improved to some extent by the reduced capacitance of the new batch of capacitor banks. If this is not enough, rectifiers with lower junction capacitance will have to be made and used in the multipliers.

4. PROGRAM FOR NEXT QUARTER

- 4.1 Conduct electrical and environmental stress testing on 14 curved multipliers, as well as on the 12 rectangular multipliers submitted to the Night Vision Laboratory as partial shipment of the First Engineering sample, and returned after being tested there.
- 4.2 Evaluate epoxy-glass substrates from the outside supplier.
- 4.3 Develop and test means to decrease the input capacitance of the multipliers.
- 4.4 Fabricate, test and submit the next engineering sample lot of curved and rectangular multipliers.

5. PUBLICATIONS AND REPORTS

No reports or publications were made on the work associated with this program during the current quarter.

6. IDENTIFICATION OF PERSONNEL

Brief descriptions of the background of technical personnel involved were included in the preceding Quarterly Progress Reports.

During the Fifth quarter of the program the following persons worked in their area of responsibility:

<u>INDIVIDUAL</u>	<u>RESPONSIBILITY</u>	<u>HRS. SPENT</u>
Dr. M. Korwin - Pawlowski	Program Manager	212
G. Gordon	Senior Electronic Engineer	35
D. Platt	Manager, Quality Assurance and Control, High Voltage Products	81
D. Archard	Senior Test Technician	52
K. Cram	Draftsman	9
V. Glenn	Q.C. Inspector	16
C. Grills	Senior Engineering Technician	10
L. Macklin	Draftsman	24
F. Treverton	Senior Test Technician	39
	Manufacturing Personnel	17

TSK 25-260

DIMENSIONING OF CURVED BANK CAPACITORS

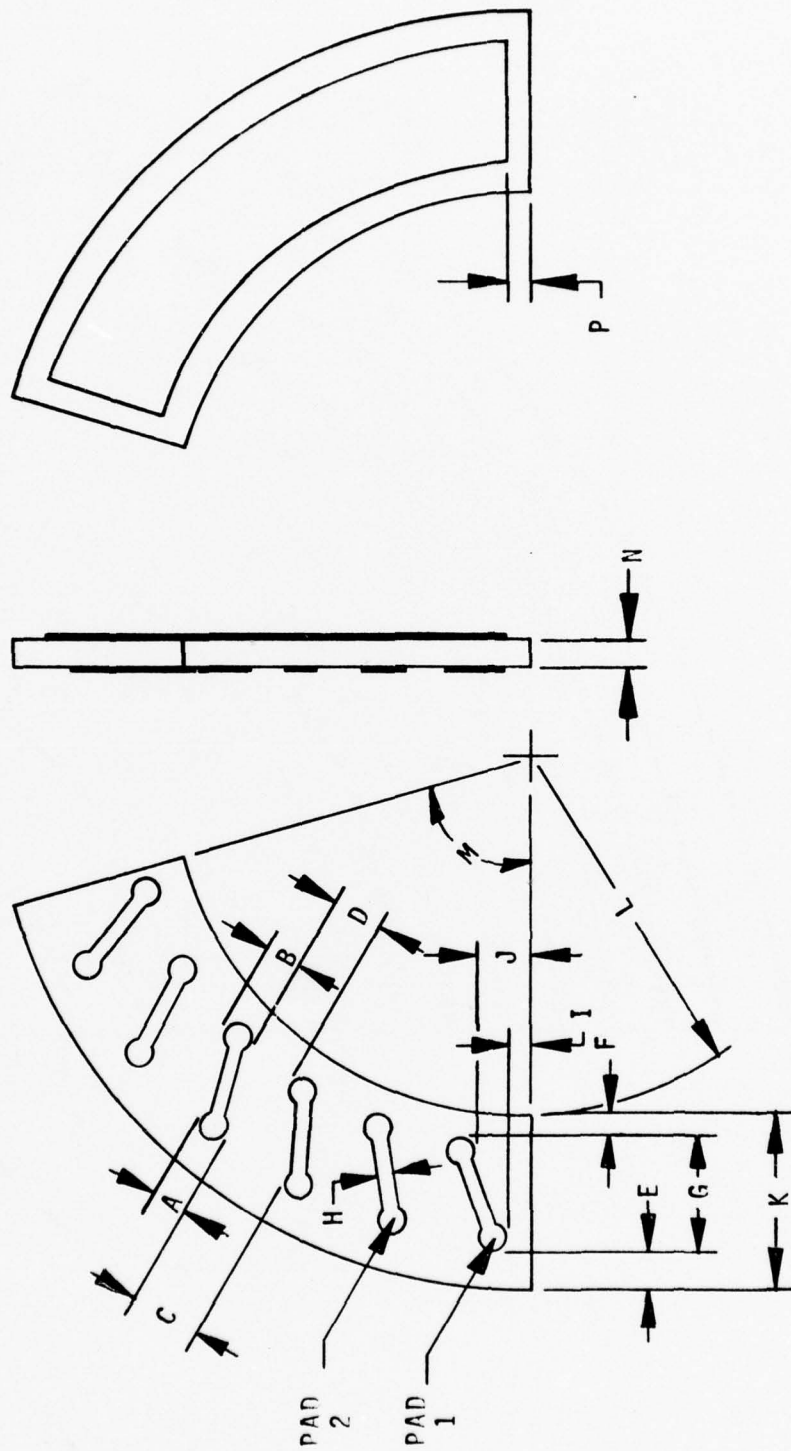


FIG. 1

RESULTS OF INSPECTION OF ANGULAR DIMENSIONS  
FOR TSK 25 - 260 CAPACITOR BANK SAMPLES

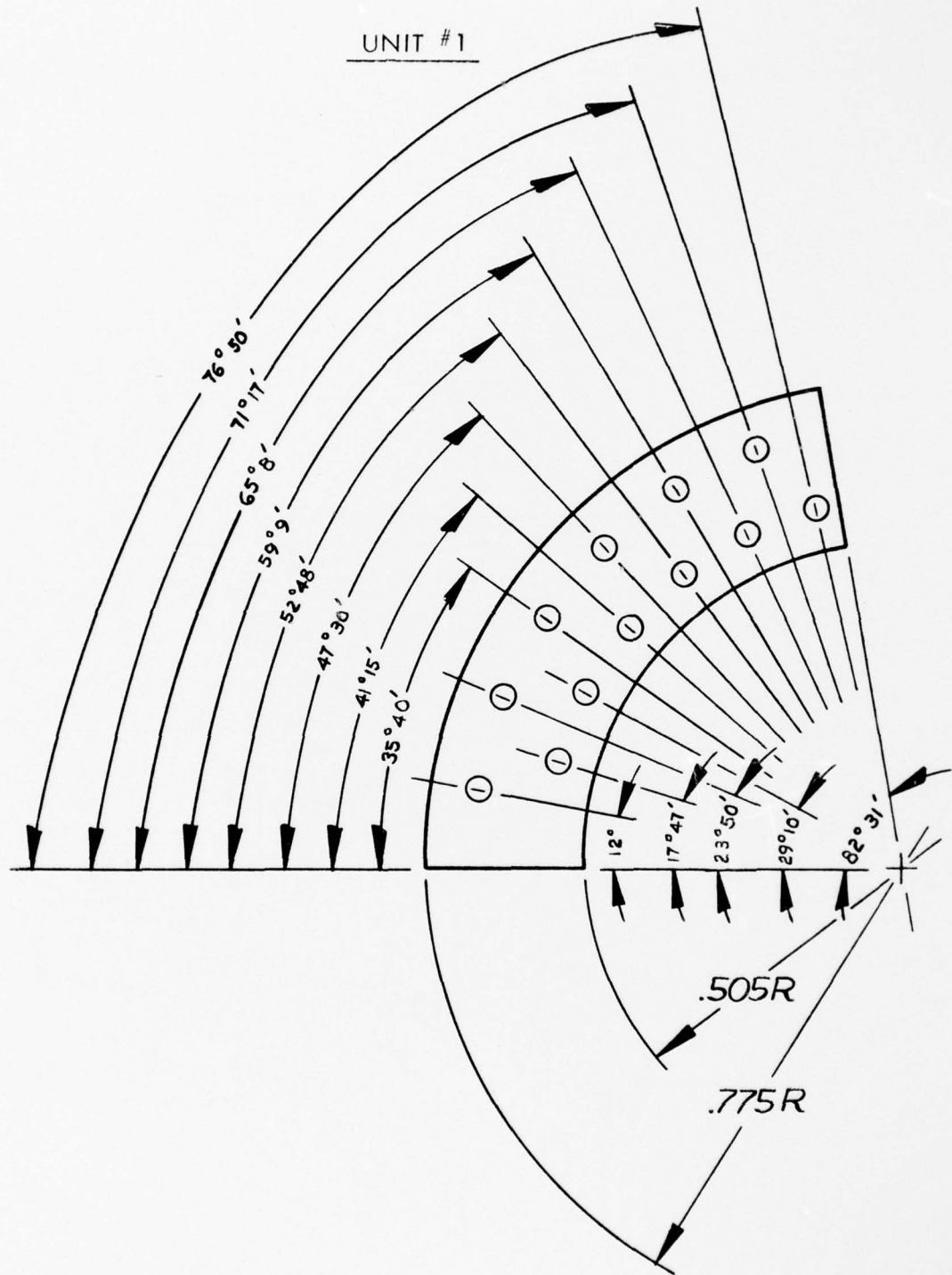


FIG. 2A  
(14)

RESULTS OF INSPECTION OF ANGULAR DIMENSIONS  
FOR TSK 25 - 260 CAPACITOR BANK SAMPLES

UNIT #2

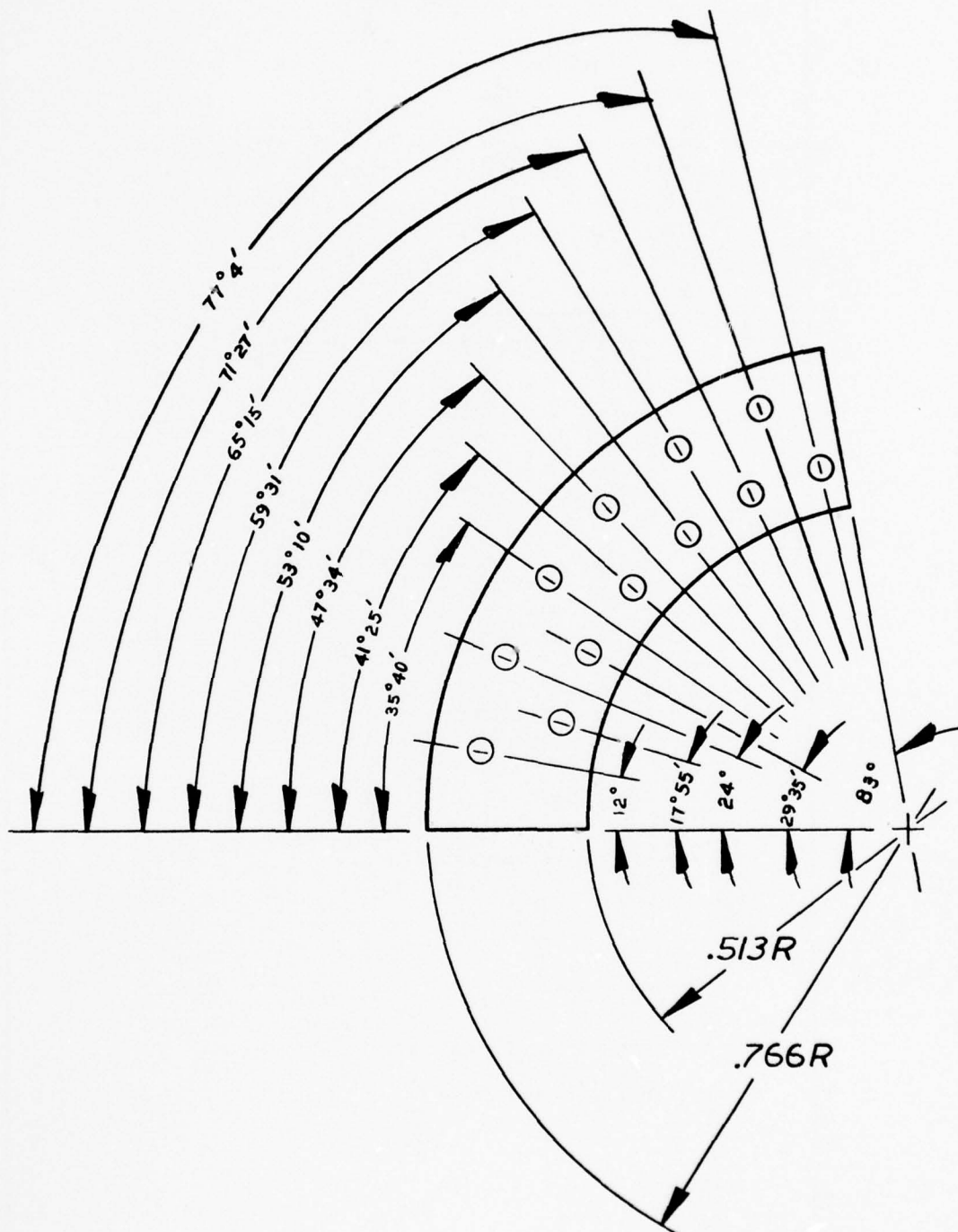


FIG. 2B  
(15)

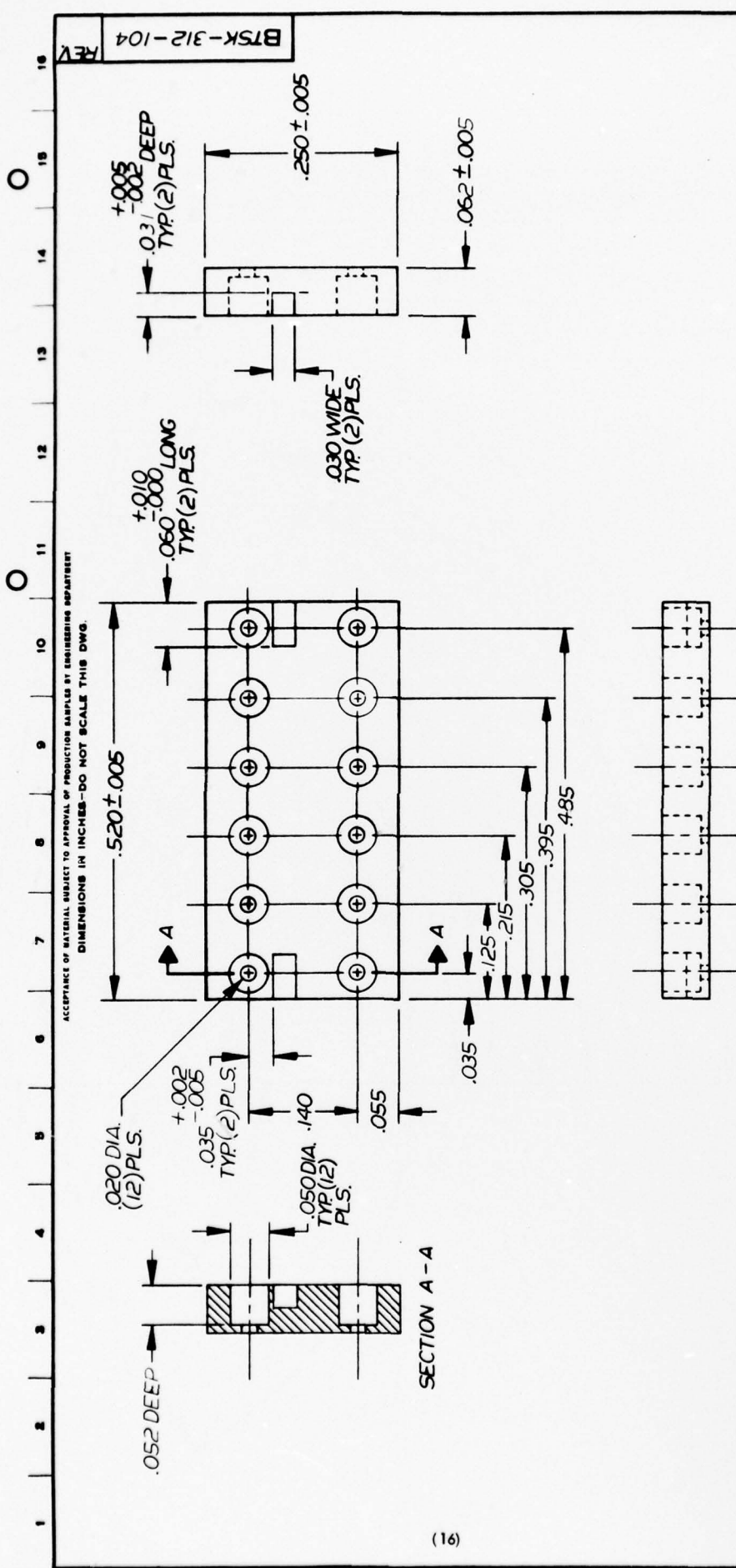
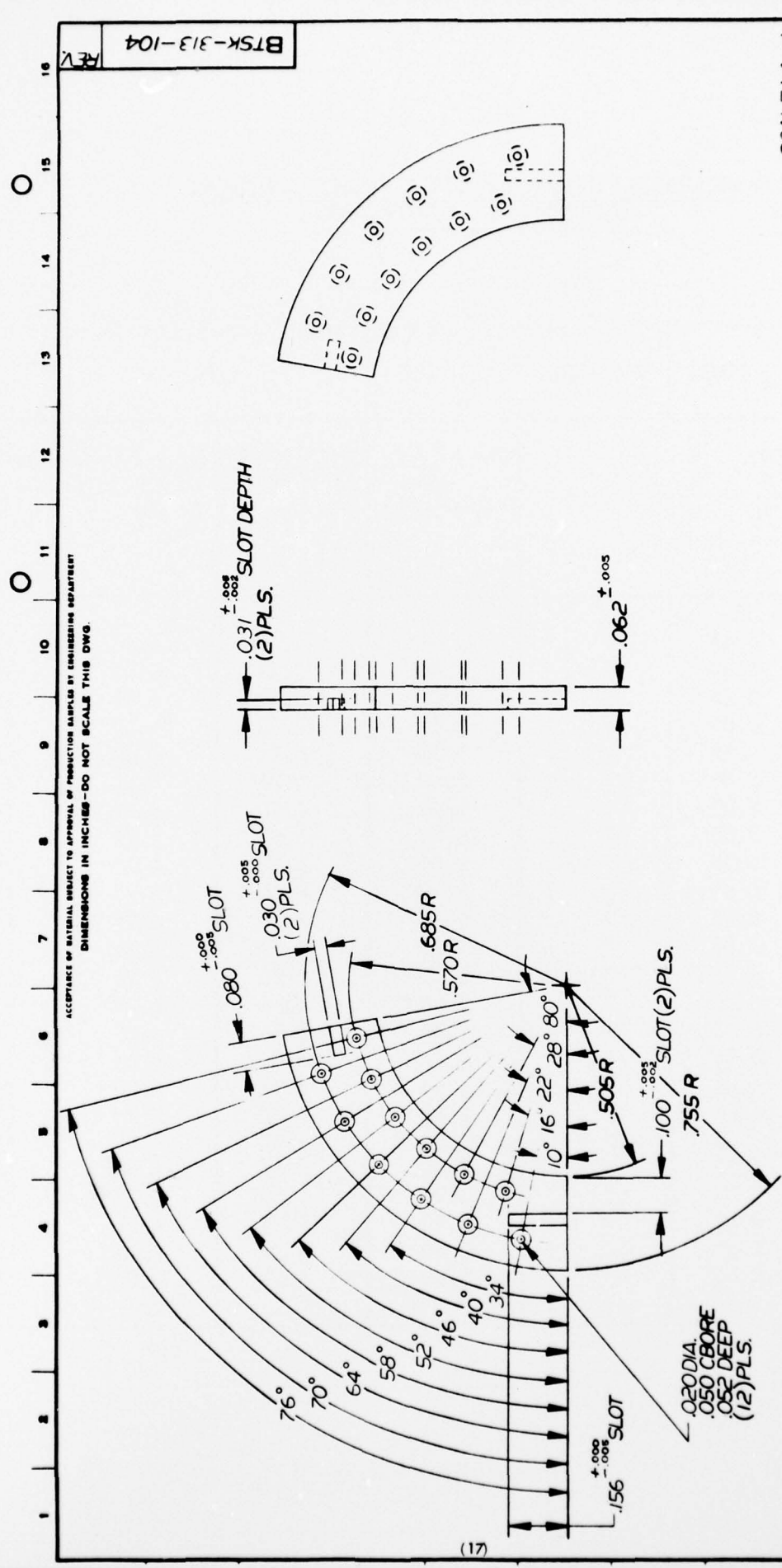


FIG. 3 SCALE: 8=1

APPROVED		SUBSTRATE PLATE (MOD. 1)		L. WACKLIN DIN. 9/10/77 MATERIAL: GLASS EPOXY, G-10 REV. 1	
TOLERANCES UNLESS OTHERWISE SPECIFIED		FRACTIONS		DECIMAL	
: .002		: .002		: .030	
ANGLES		: 0°30'		: 0°30'	



SUBSTRATE PLATE (MOD. #2)		TOLERANCES UNLESS OTHERWISE SPECIFIED		MATERIAL GLASS EPOXY, G-10	
FRACTIONS		DECIMAL		ANGLES	
.002		.002		0° 30'	
.030		.030		0° 30'	
BT SK-313-104		REV.		REV.	

ELECTRICAL CHARACTERISTICS OF RECTANGULAR  
MULTIPLIERS TSK 312 - 000

Unit #	$V_{o,}$ (kV)	$V_{r,}$ (Vpp)	$V_{o,}$ (kV)	$C_i$ (pF)		$i_{c,}$ ( $\mu$ A)
	@ $V_i$ = 1 kV $f$ = 40 kHz $I_L$ = 0		@ $V_i$ = 1 kV $f$ = 40 kHz $I_L$ = 500nA	@ $V_i$ = 500 V $f$ = 20 kHz $I_L$ = 0	$V_i$ = 1 kV $f$ = 20 kHz $I_L$ = 0	$V_i$ = 1 kV $f$ = 20 kHz $I_L$ = 0
32	5.85	7	5.80	6.79	6.04	130
33	5.85	7	5.80	6.73	6.00	130
34	5.85	7	5.80	6.73	6.00	130
35	5.85	7	5.80	7.05	6.32	138
36	5.85	7	5.80	6.74	6.00	130
37	5.85	7	5.80	6.96	6.23	135
38	5.85	7	5.80	6.60	5.84	140
39	5.85	7	5.80	6.83	6.12	135
41	5.85	7	5.80	6.83	6.12	135
42	5.85	7	5.80	6.60	5.95	138
43	5.85	7	5.80	6.98	6.28	140
44	5.85	7	5.80	6.57	5.86	143
46	5.85	7	5.80	6.95	6.25	155
47	5.85	7	5.80	6.94	6.20	N/A
48	5.85	7	5.80	6.96	6.23	140
49	5.85	7	5.80	6.80	6.04	140
51	5.85	7	5.80	6.93	6.20	130
52	5.85	7	5.80	6.70	5.96	135
53	5.85	7	5.80	6.71	6.08	135
54	5.85	7	5.80	6.54	5.88	135
56	5.85	7	5.80	6.90	6.20	140
57	5.85	7	5.80	6.82	6.08	140
58	5.85	7	5.80	6.95	6.22	135
65	5.85	7	5.80	6.51	5.87	165

Table 1

ELECTRICAL CHARACTERISTICS OF CURVED  
MULTIPLIERS TSK 313 - 000

Unit #	$V_o$ , (kV)	$V_r$ , (V)	$V_o$ , (kV)	$C_i$ (pF)		$i_c$ , ( $\mu$ A)
	@ $V_i$ = 1 kV $f$ = 40 kHz $I_L$ = 0		@ $V_i$ = 500 V $f$ = 20 kHz $I_L$ = 500nA	@ $V_i$ = 500 V $f$ = 20 kHz $I_L$ = 0	$V_i$ = 1 kV $f$ = 20 kHz $I_L$ = 0	$V_i$ = 1 kV $f$ = 20 kHz $I_L$ = 0
1	5.90	8	5.85	N/A	N/A	N/A
2	5.90	8	5.85	9.43	8.74	188
3	5.90	8	5.85	9.32	8.65	158
4	5.90	8	5.85	8.13	7.32	143

Table 2

OUTPUT VOLTAGE OF RECTANGULAR MULTIPLIERS TSK 312 - 000  
AFTER ENVIRONMENTAL STRESS TESTS

Unit #	$V_o$ , (kV) @ $V_i = 1$ kV, $f = 40$ kHz							
	@ $T = 52^\circ\text{C}$		@ $T = -54^\circ\text{C}$		After Thermal Shocks 25 x (-65 to +71°C)		After Storage At - 65 and +71°C	
	$I_L = 0$	$I_L = 500$ nA	$I_L = 0$	$I_L = 500$ nA	$I_L = 0$	$I_L = 500$ nA	$I_L = 0$	$I_L = 500$ nA
32	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
34	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
35	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
38	5.80	5.75	5.85	5.80	5.80	5.80	N/A	N/A
42	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
46	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
51	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
53	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
56	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75
58	5.80	5.75	5.85	5.80	5.80	5.75	5.80	5.75

Table 3

MECHANICAL INSPECTION DATA FOR TSK 25 - 260 CAPACITOR BANK SAMPLES

UNIT 1

PAD #	1	2	3	4	5	6
Dimensions in inches						
A	.0460	.0492	.0463	.0474	.0473	.0461
B	.0469	.0456	.0474	.0487	.0454	.0453
E	.0343	.0317	.0344	.0369	.0400	.0437
F	.0530	.0505	.0487	.0436	.0376	.0333
H	.0242	.0257	.0251	.0253	.0220	.0208
K	.2530					
N	.0420					
P	.0358 min., .0933 max.					

NOTE: See Figure 1 for dimensioning

Table 4A

MECHANICAL INSPECTION DATA FOR TSK 25 - 260 CAPACITOR BANK SAMPLES

UNIT 2

PAD #	1	2	3	4	5	6
Dimensions in inches						
A	.0486	.0452	.0450	.0482	.0456	.0451
B	.0454	.0446	.0459	.0429	.0406	.0381
E	.0327	.0320	.0351	.0372	.0385	.0432
F	.0520	.0502	.0484	.0423	.0406	.0381
H	.0236	.0221	.0249	.0267	.0215	.0207
K	.2496					
N	.0410					
P	.0349 min., .0949 max.					

NOTE: See Figure 1 for dimensioning

Table 4B

ELECTRICAL TEST DATA FOR TSK 25 - 260  
CURVED CAPACITOR BANK SAMPLES

UNIT #	PAD #	C <sub>x</sub> @ 0kV (pF)	D.F. %	C <sub>x</sub> @ 6 kV (pF)	V <sub>B</sub> (kV)
1	1	88.8	0.10	62.6	13.5
	2	90.4	0.10	63.3	9.0
	3	91.0	0.11	63.7	12.2
	4	94.4	0.10	66.1	11.9
	5	91.4	0.10	64.0	10.4
	6	78.7	0.11	55.2	Broke
2	1	85.9	0.11	60.1	9.0
	2	87.6	0.11	61.2	9.0
	3	89.3	0.11	62.5	7.5
	4	92.0	0.11	64.4	9.6
	5	83.5	0.12	58.5	8.8
	6	77.4	0.12	54.2	9.0
AVERAGE		87.5	0.11	61.3	10.0

Table 5

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